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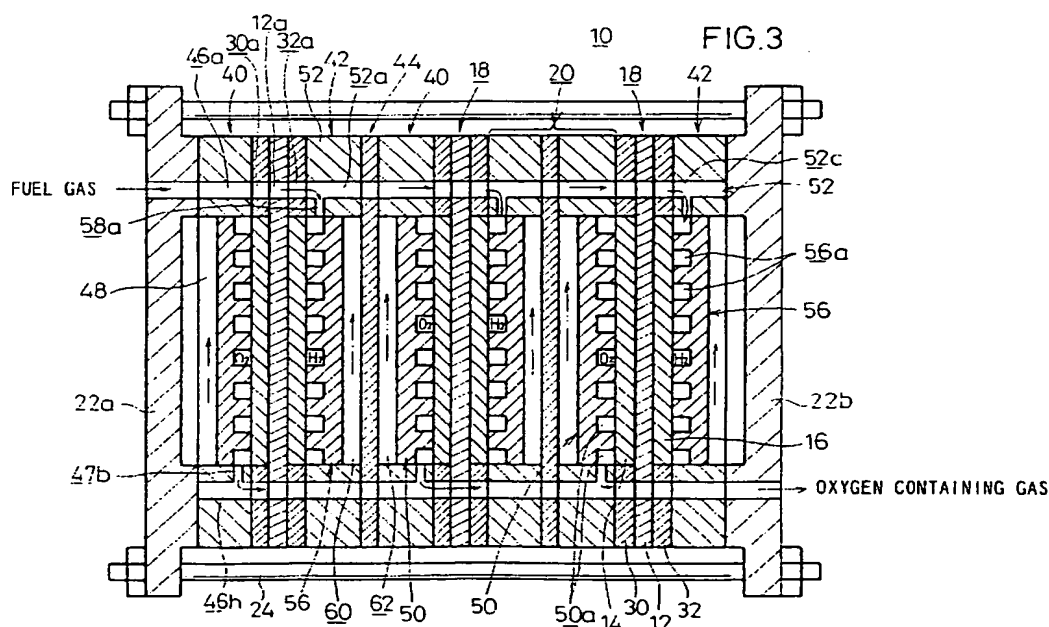
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(54) Fuel cell stack with dual cooling system

(57) A fuel cell unit (18) in which a hydrogen-side (anode) electrode (16) and an air-side (cathode) electrode (14) are disposed in facing relation to each other with an electrolyte membrane (12) interposed therebetween, and wherein a separator (20) is provided for supporting said fuel cell structure interposed therebetween. The separator has, independently disposed therein, a first cooling passage (60) through which a first cooling

medium, generally composed of water, is introduced for cooling the hydrogen-side electrode, and a second cooling passage (62) through which a second cooling medium having a melting point below that of water is introduced for cooling the air-side electrode. Accordingly, a melting operation for the first cooling medium can be easily and swiftly carried out, while the fuel cell unit itself remains simple in structure.



## Description

The present invention is directed to a fuel cell structure in which an anode electrode and a cathode electrode are disposed in facing relation to each other with an electrolyte membrane interposed therebetween, and wherein a separator is provided for supporting the fuel cell structure interposed therebetween.

### Description of the Related Art:

There have been developed fuel cells comprising, for example, a plurality of stacked fuel cell units each having an anode and a cathode provided in opposing relation with an electrolyte membrane sandwiched therebetween, the fuel cell units further being interposed between separators. Such fuel cells are being put to practical use in a variety of applications.

Such types of fuel cells, for example, are structured such that a hydrogen gas (i.e. a fuel gas) which is generated by a methanol vapor reforming is supplied to a anode electrode, and an oxygen-containing gas (air) is supplied to a cathode electrode, whereby the hydrogen gas becomes ionized and flows through a solid polymer electrolyte membrane, thereby generating electrical energy out of the fuel cell.

In this case, in order that efficient generation of electrical power from the fuel cell can be exhibited, it is necessary to cool the anode and cathode electrodes of the fuel cell. For this purpose, for example, a structure wherein conduits for cooling water are provided in the separators, and wherein cooling water is supplied through said conduits, has been widely employed.

However, with the fuel cell having the structure described above, a problem has arisen in that when the fuel cell is used in especially cold regions, the cooling water in the fuel cell can become frozen. As a result, prior to initiating operation of the fuel cell, it becomes necessary to undertake an operation for melting the frozen cooling water, and such an operation is both troublesome and time consuming.

The present invention, at least in its preferred forms, has the object of addressing and solving the aforementioned problems, wherein a melting operation for melting a cooling medium can be easily and swiftly carried out, yet while offering a fuel cell having a simplified structure.

According to the present invention there is provided a fuel cell, comprising an anode part, a cathode part and a separator structure, the separator structure having a first cooling conduit through which a first cooling medium flows for cooling an anode electrode side, and a second cooling conduit through which a second cooling medium flows for cooling a cathode electrode side of the fuel cell, wherein one of the first cooling medium and the second cooling medium has a lower melting point than the other cooling medium.

For example, the first cooling medium can comprise water, and the second cooling medium can be a sub-

stance having a melting point below that of water.

Accordingly, when the cooling medium becomes frozen in the first cooling conduit, the second cooling medium having a melting point below that of the first cooling medium, in a non-frozen state, is caused to flow through the second cooling conduit, and thereby heat is conducted from the second cooling medium to the first, so that the frozen cooling medium can be easily melted. Notwithstanding this, the overall structure of the fuel cell can remain simple and efficient.

Preferably, when freezing of the first cooling medium is detected, the second cooling medium is heated via a heating means, and a melting operation for melting the frozen cooling medium is even more quickly and reliably accomplished. The water freezing detection can be performed using a pressure meter for detecting cooling medium pressure and/or a flow rate meter for detecting the flow rate of the cooling medium.

Preferably, the fuel cell comprises a plurality of fuel cell units between which are interposed separator unit(s) which define at least part of the first and second conduits. Thus, the coolant flowing in the conduits within the separator unit may cool the anode of one fuel cell unit and the cathode or an adjacent fuel cell unit.

An embodiment of the invention will now be described, by way of example only and with reference to the accompanying drawings:-

FIG. 1 illustrates, in outline perspective view, an embodiment of the fuel cell according to the present invention.

FIG. 2 illustrates an exploded perspective view of one part of the fuel cell shown in FIG. 1.

FIG. 3 is an orthogonal plan view cut along line III-III in FIG. 1.

FIG. 4 is an explanatory outline of the circulatory routes through which the first and second cooling mediums are circulated.

FIG. 5 is an orthogonal plan view cut along line V-V in FIG. 1.

FIG. 6 is an orthogonal plan view cut along line VI-VI in FIG. 1.

FIG. 7 is an orthogonal plan view cut along line VII-VII in FIG. 1.

FIG. 1 illustrates, in outline perspective view, an embodiment of the fuel cell according to the present invention, whereas FIG. 2 shows an exploded perspective view of one part of the fuel cell shown in FIG. 1.

A fuel cell 10 is made up of fuel cell unit 18 comprising an air-side (cathode) electrode 14 and a hydrogen-side (anode) electrode 16 which are disposed in confronting relation to each other and having sandwiched therebetween a solid polymer electrolyte membrane 12, together with separators 20 which support in sandwiched relation therebetween a plurality of such fuel cell units 18. The fuel cell unit 18 and separators 20 are fixed together unitarily by opposing end plates 22a, 22b and four tie rods 24.

As shown in FIG. 2, the upper side of the electrolyte

membrane 12 has disposed therein a fuel gas inlet hole 12a, an air-side electrode cooling medium (second cooling medium) discharge hole 12b, a cooling water (first cooling medium) discharge hole 12c and an oxygen-containing gas inlet hole 12d. The lower part of the electrolyte membrane has disposed therein a fuel gas discharge hole 12e, an air-side electrode cooling medium inlet hole 12f, a cooling water inlet hole 12g and an oxidizing gas discharge hole 12h.

On both sides of the fuel cell unit 18 are arranged a first gasket 30 and a second gasket 32. The first gasket 30 includes a large opening 34 for accommodating the air-side electrode 14, and the second gasket 32 has a large opening 36 therein for accommodating the hydrogen-side electrode 16. The first and second gaskets 30, 32 have respectively disposed at an upper portion thereof, fuel gas introduction holes 30a, 32a, air-side electrode cooling medium discharge holes 30b, 32b, cooling water discharge holes 30c, 32c and oxygen-containing gas inlet holes 30d, 32d. In addition, respectively disposed on a lower portion thereof are fuel gas discharge holes 30e, 32e, air-side electrode cooling medium inlet holes 30f, 32f, cooling water inlet holes 30g, 32g and oxygen-containing gas discharge holes 30h, 32h.

The separators 20 are made up of a first air-side electrode separator part 40, a second hydrogen-side electrode separator 42, and a partition plate 44 which is sandwiched between the first and second separator parts 40, 42.

A first manifold plate 46 which makes up part of the first separator part 40, is constructed as a rectangular flat plate, wherein in a middle portion thereof, a large opening 48 is provided. On the upper side of the first manifold plate 46 are disposed a fuel gas inlet hole 46a, an air-side electrode cooling medium discharge hole 46b, a cooling water discharge hole 46c, and an oxygen-containing gas inlet hole 46d. On the lower side of the first manifold plate 46 are disposed a fuel gas outlet hole 46e, an air-side electrode cooling medium inlet hole 46f, a cooling water inlet hole 46g and an oxygen-containing gas discharge hole 46h. Recesses 47a, 47b which are disposed in the first manifold plate 46 offset from the air-side electrode 14 communicate with the two holes 46d and 46h which are disposed in positions mutually angularly opposed from one another. The recesses 47a, 47b further communicate with each other through the opening 48 (see FIG. 3 and FIG. 5).

An oxygen-containing gas flow control plate 50 (cathode-side element) is fitted in the opening 48 of the first manifold plate. The oxygen-containing gas flow control plate 50 has one side thereof which is flat, and the other side has serpentine pathways 50a formed thereon, the serpentine pathways providing communication between the hole 46d and the hole 46h. The oxygen-containing gas flow control plate 50 is formed from a dense material, and more specifically can be made from graphite-carbon, stainless steel, or conductive metals having corrosion resistant properties, such as

the nickel alloy Inconel (trademark), other nickel alloys, or further from conductive rubber or conductive resins.

The holes 46b, 46f of the first manifold plate 46 are positioned offset from the second separator part 42 side, and intercommunicate with each other through the recesses 49a, 49b and the opening 48 (see FIG. 6 and FIG. 7).

The second separator part 42 is constructed in similar fashion as the first separator part 40, and the second manifold plate 52 includes a fuel gas flow control plate (anode-side element) 56 fitted into the opening 54 of the second manifold plate 52.

On the upper portion of the manifold plate 52 are disposed a fuel gas inlet hole 52a, an air-side electrode cooling medium discharge hole 52b, a cooling water discharge hole 52c, and an oxygen-containing gas inlet hole 52d, whereas on the lower portion thereof are disposed a fuel gas discharge hole 52e, and air-side electrode cooling medium inlet hole 52f, a cooling water inlet hole 52g, and an oxygen-containing gas discharge hole 52h. Holes 52a and 52e communicate through recesses 58a, 58b (see FIG. 3 and FIG. 5), and in addition, holes 52c and 52g communicate with the opening 54 through recesses 58c, 58d (see FIG. 6 and FIG. 7).

The fuel gas flow control plate 56 is flat on one side thereof, while on the other surface thereof is formed with a serpentine pathway 56a. In order that water (the first cooling medium) which is supplied to the flat side of the control plate 56 can further be supplied to the hydrogen electrode 16, the fuel gas flow control plate 56 is formed from a conductive water-permeable material, and more specifically, may be constructed of porous sintered carbon, a conductive porous sintered metal, porous conductive rubber, a porous conductive resin, or other various porous materials, or composites thereof. If the fuel gas flow control plate 56 is formed of porous sintered carbon, it is preferable that the plate have a porosity of less than 70% and a pore size of less than 40  $\mu\text{m}$ , so that dripping of water is prevented.

Further, the fuel gas flow control plate 56 ideally should be constructed as a porous body which has been made water repellant to improve durability. In this case, the fuel gas flow control plate 56 is subjected to a water repellant treatment, for example, by immersing the flow control plate in a dispersion solution of PTFE (polytetrafluoroethylene) adjusted at a predetermined concentration, and then drying at room temperature, followed by firing at 300 to 380  $^{\circ}\text{C}$ .

The partition plate 44 is composed of dense and conductive graphite carbon, stainless steel, a conductive metal having a corrosion resistance such as a nickel alloy, conductive rubber, conductive resin, or composites thereof. The partition plate 44, at an upper portion thereof, is provided with a fuel gas inlet hole 44a, an air-side electrode cooling medium discharge hole 44b, a cooling water discharge hole 44c and an oxygen-containing gas inlet hole 44d. On the lower portion of the partition plate 44, there are disposed a fuel gas discharge hole 44e,

an air-side electrode cooling medium inlet hole 44f, a cooling water inlet hole 44g and an oxygen-containing gas discharge hole 44h.

As shown in FIG. 3, the separator 20 has a first passage for introducing cooling water for cooling the hydrogen-electrode 16 side between the partition plate 44 and the fuel gas flow control plate 56. In addition, a second cooling passage 62 is disposed for introducing a second cooling medium for cooling the air-side electrode 14 between the partition plate 44 and the oxygen-containing gas flow control plate 50.

The first and second cooling passages 60, 62 are respectively independent, wherein the first cooling medium, i.e. water, is supplied through the first cooling passage 60, and the second cooling medium, having a melting point below that of the first cooling medium, is supplied through the second cooling passage.

As for the second cooling medium, in particular, any of the following may be used, wherein the respective melting temperatures, under ordinary pressure are shown in parenthesis: methanol (-97.78 ° C), ethanol (-114.5 ° C), propanol (-127° C), isopropanol (-89.5° C), 1-butanol (-89.53° C), 2-methyl-1-propanol (-108° C), 2-butanol (-114.7° C), 1-hexanol (-44.6° C), 1-octanol (-14.9° C), 2-ethyl-hexanol (-76° C), methane (-182.48°C), ethane (-183.6°C), propane (-187.69° C), ethylene-glycol (-12.6 ° C), propylene-glycol (-60 ° C), ethyl-ether (-116.3° C), toluene (-95° C), ammonia (-77.7° C), methylamine (-93.46° C), and ethylamine (-81° C).

As shown in FIG. 4, the fuel cell is arranged with a first circulatory route 70 for circulating the first cooling medium comprised of water to the first cooling passage 60, and a second circulatory route circuit 72 for circulating the second cooling medium to the second cooling passage 62.

The first circulatory route 70 has arranged therein a water tank 74, wherein the water tank 74 communicates with the fuel cell through the first circulatory passage 76. In the first circulatory passage 76, a circulating pump 78 for supplying water to the fuel cell from the water tank 74, a pressure measuring device 80 for detecting water pressure, and a flow rate measuring device 82 for detecting flow rate are disposed. The pressure measuring device 80 and/or the flow rate measuring device 82 serve as a freezing detection means for detecting a frozen state of the water.

The second circulatory route 72 has arranged therein a reserve tank 84 for the second cooling medium, wherein the reserve tank 84 and the fuel cell 10 communicate with each other through a second circulatory passage 86. In the second circulatory passage 86, a circulating pump 88 for a low melting point cooling medium, for supplying the second cooling medium to the fuel cell 10 from the reserve tank 84, and a heat transfer device (heating means) 90 for supplying heat to the second cooling medium, for the purpose of melting the water when it is detected that the water is in a frozen state,

are respectively disposed.

A description of the operation of the fuel cell 10, constructed as indicated above, shall now be given.

As shown in FIG. 3, when the fuel gas (hydrogen gas) is supplied to the fuel cell 10, the fuel gas passes through the hole 46a of the first manifold plate 46 of the first separator part 40, and holes 30a, 12a and 32a of the fuel cell unit 18, to reach the hole 52a of the second manifold plate 52 of the second separator part 42. The fuel gas then flows from the hole 52a and recess 58a through the passage 56a of the fuel gas flow control plate 56, and is supplied to the hydrogen electrode 16 of the fuel cell unit, and then is discharged through the recess 58b.

As shown in FIG. 5, the oxygen-containing gas is supplied through the hole 46d of the first manifold plate 46, and is introduced into the passage 50a of the oxygen-containing gas flow control plate 50 from hole 46d and recess 47a, and therefrom is supplied to the air-side electrode 14 of the fuel cell unit 18. Further, any unused oxygen-containing gas, as shown in FIG. 3, is discharged to the outside through the hole 46h of the first manifold plate 46, and any unused fuel gas, as shown in FIG. 5, is discharged to the outside through the hole 52e of the second manifold plate 52.

On the other hand, the first cooling medium composed of water, as shown in FIG. 4, is supplied to the fuel cell 10 from the water tank 74 and via the first circulatory passage 76 under operation of the pump 78. The water, as shown in FIG. 7, reaches the hole 52g of the second separator part 42 from the hole 46g of the first separator part 40, and the holes 30g, 12g and 32g of the fuel cell unit 18, and from the recess 58 which communicates with the hole 52g, is introduced to the partition plate 44 and the fuel gas flow control plate 56, or in other words, to the first cooling passage 60, and flows in a direction from the bottom to the top of the cooling passage 60.

At this time, since the fuel gas flow control plate 56 is formed of a water permeable material (porous body), the water which is introduced through the first cooling passage 60 permeates the fuel gas flow control plate 56, and can thereby directly humidify the fuel gas supplied through the passage 56a and the hydrogen electrode 16.

Furthermore, the second cooling medium, as shown in FIG. 4, is supplied to the fuel cell 10 from the reserve tank 84 through the second circulatory passage 86 under operation of the pump 88. As shown in FIG. 6, the second cooling medium is supplied to the hole 46f of the first separator part 40, and from the recess 49 which communicates therewith, is introduced in a direction from the bottom to the top of the second cooling passage 62 of the separator 20. As shown in FIG. 7, the second cooling medium is returned to the second circulatory passage 86 through the hole 46b of the first manifold plate 46, whereas the water which is introduced into the first cooling passage, as shown in FIG. 6, is returned

to the first circulatory passage 76 through the recess 58c of the second manifold plate 52.

Incidentally, when the fuel cell 10 is employed in regions having cold climates, there is a tendency for the first cooling medium composed of water in the interior of the fuel cell 10 to become frozen. To cope with this difficulty, the present embodiment employs, in the separator, a first cooling passage 60 through which the first cooling medium is introduced, and a second cooling passage 62 through which the second cooling medium is introduced, wherein the second cooling medium is a substance having a lower melting point than the first cooling medium which is generally composed of water.

As a result of this arrangement, even if the water becomes frozen, because the second cooling medium remains in an unfrozen state and flows through the second cooling passage 62, heat exchange occurs across the partition plate 44 which is sandwiched between the frozen water and the second cooling medium. Accordingly, with this simple structure, the frozen water can be easily melted.

Still further, with the present embodiment as shown in FIG. 4, first and second circulatory routes 70 and 72 are provided. Thereby, when a frozen condition of the water is generated in the fuel cell, an indicated pressure value from the pressure measuring device 80 disposed in the first circulatory route 70 becomes greater than a predetermined value, together with the flow rate meter 82 no longer detecting a water flow, so that the frozen condition of the water can be automatically detected.

At this time, based on the detection result from the pressure measuring device and/or the flow rate measuring device, the heat exchange device 90 disposed in the second circulatory route 72 is operated. Accordingly, the second cooling medium which is supplied to the fuel cell 10 through the second circulatory passage is heated by the heat exchange device 90, and water which is frozen inside the fuel cell 10 can be quickly and reliably melted.

As set forth and described above, in the fuel cell according to the present invention, when a first cooling medium which is generally composed of water becomes frozen in the first cooling path of the separator, a second cooling medium having a lower melting point than water flows through the second cooling path in an unfrozen state, and thereby heat exchange is conducted with the water. As a result, with a simple structure, the water can be easily and efficiently melted.

## Claims

1. A fuel cell (10) comprising an anode part (16), a cathode part (14) and a separator structure, the separator structure having a first cooling conduit (60) through which a first cooling medium flows for cooling the anode part and a second cooling conduit (62) through which a second cooling medium flows

for cooling the cathode part, wherein one of the first cooling medium and the second cooling medium has a lower melting point than the other cooling medium.

2. A fuel cell as claimed in claim 1, wherein one of said first cooling medium and said second cooling medium is water and the other has a melting point below that of water.
3. A fuel cell as claimed in claim 2, wherein said first cooling medium for cooling said anode part is water, and wherein said second cooling medium for cooling said cathode part is a substance having a melting point below that of water.
4. A fuel cell as claimed in claim 2 or 3, wherein said substance having a melting point below that of water is selected from the group of methanol, ethanol, propanol, isopropanol, 1-butanol, 2-methyl-1-propanol, 2-butanol, 1-hexanol, 1-octanol, 2-ethylhexanol, methane, ethane, propane, ethylene-glycol, propylene-glycol, ethyl-ether, toluene, ammonia, methylamine, and ethylamine.
5. A fuel cell as claimed in any preceding claim, further comprising:

a first circulatory route (70) for circulating said first cooling medium via said first cooling conduit (60); and

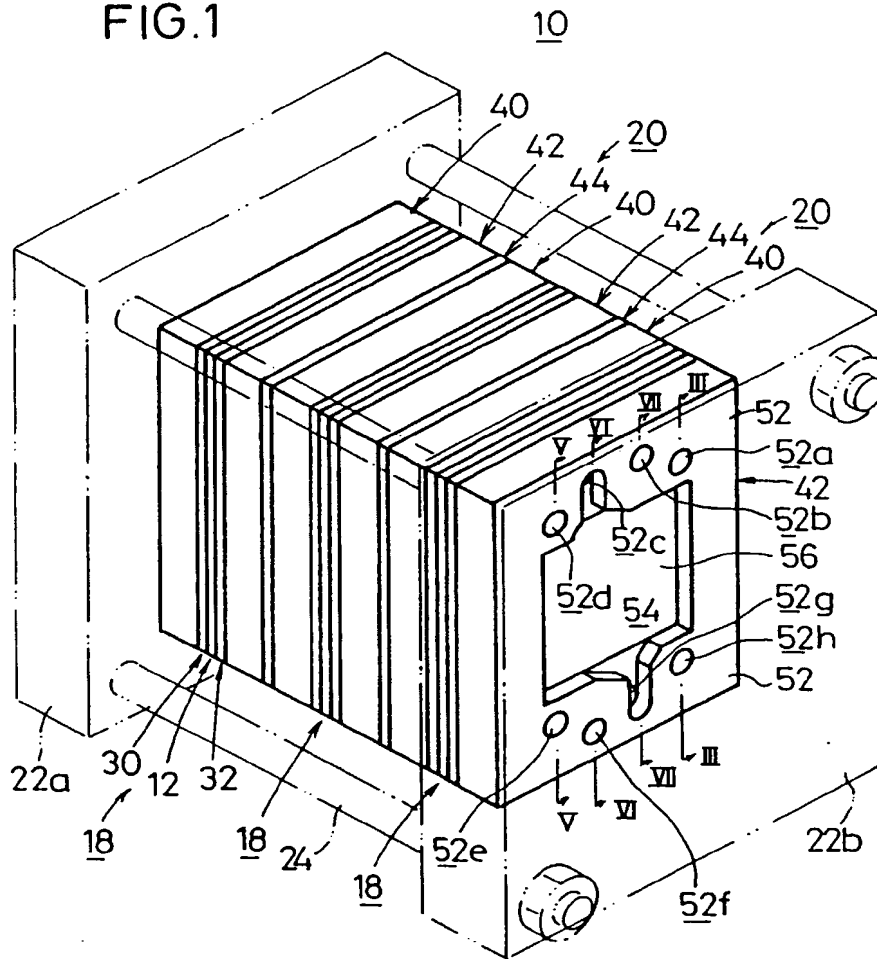
a second circulatory route (72) for circulating said second cooling medium via said second cooling conduit (62),

wherein said first circulatory route includes a freezing detection means (80, 82) for detecting whether said first cooling medium is frozen, and said second circulatory route includes a heating means (90) for conveying heat to said second cooling medium for the purpose of melting said first cooling medium when it is detected that said first cooling medium is frozen.

6. A fuel cell as claimed in claim 5, wherein said freezing detection means comprises a pressure measurement means (80) for detecting pressure in said first circulatory route and/or flow measurement means (82) for detecting a rate of flow through said first circulatory route.

7. A fuel cell as claimed in any preceding claim comprising a plurality of fuel cell units (18), each said fuel cell unit comprising an anode (16) and a cathode (14) opposing each other with an electrolyte membrane (12) interposed therebetween, wherein said first cooling conduit and said second cooling conduit are defined by a separator unit (20) interposed between adjacent fuel cell units (18).

FIG.1



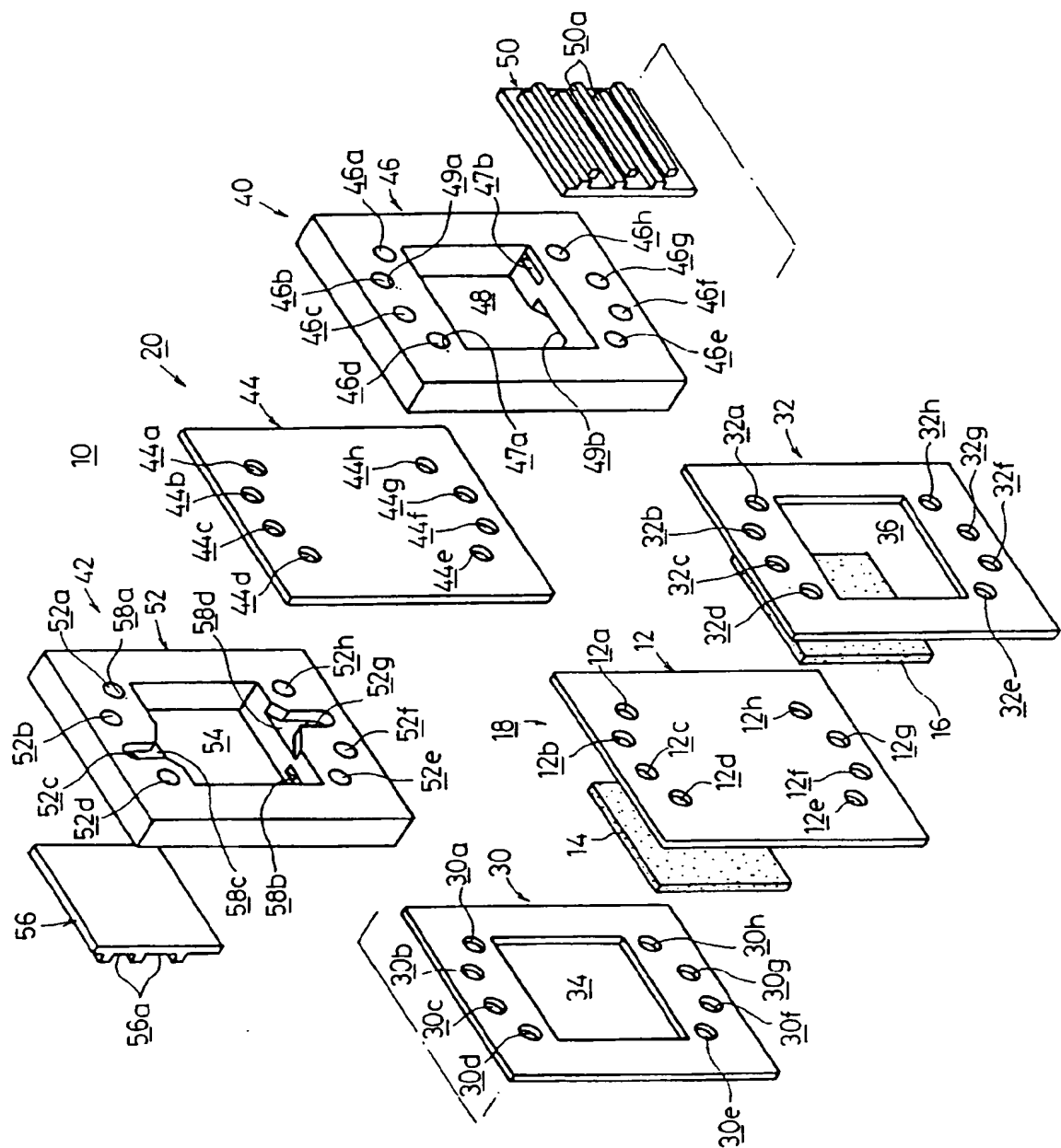
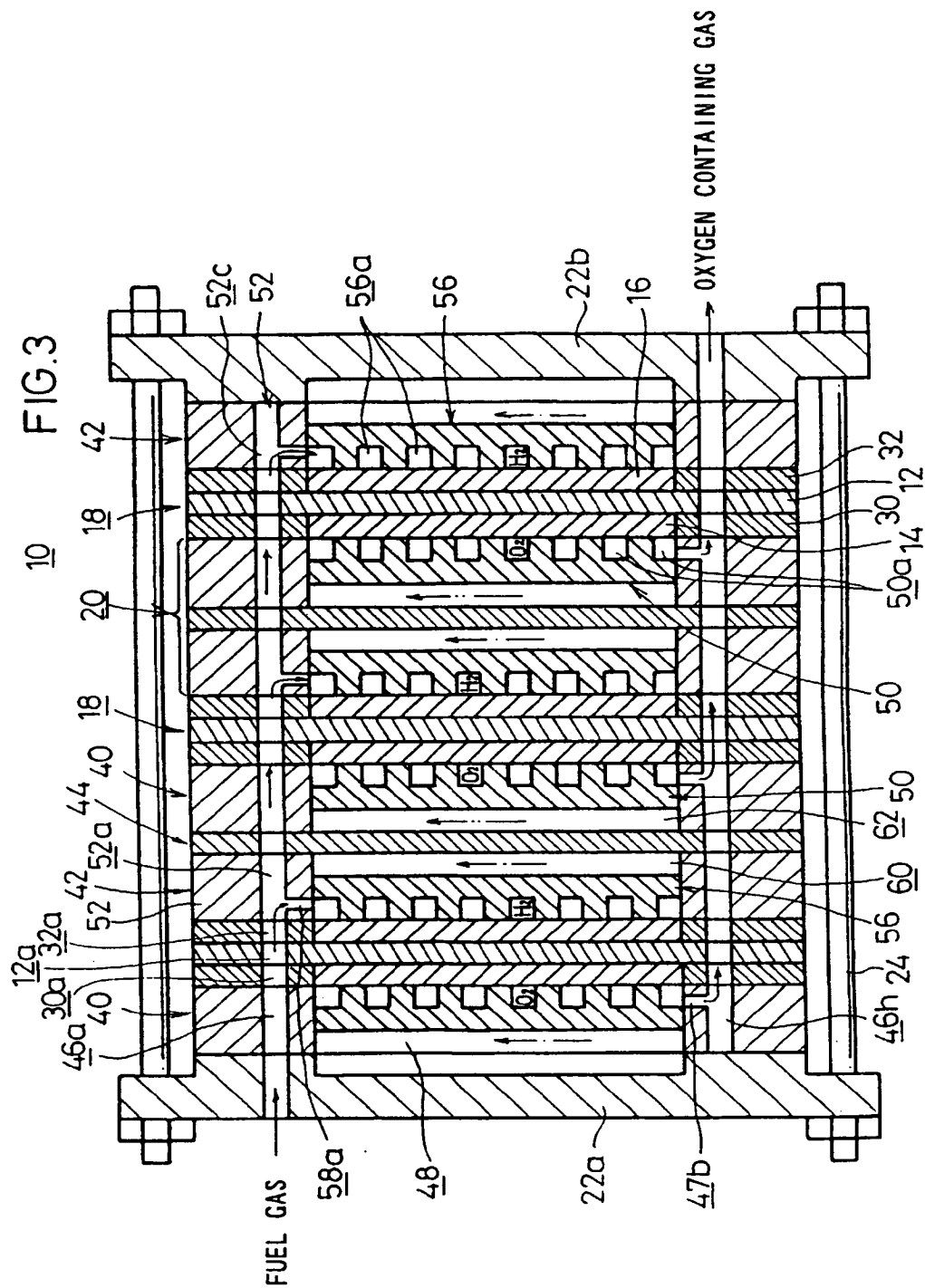
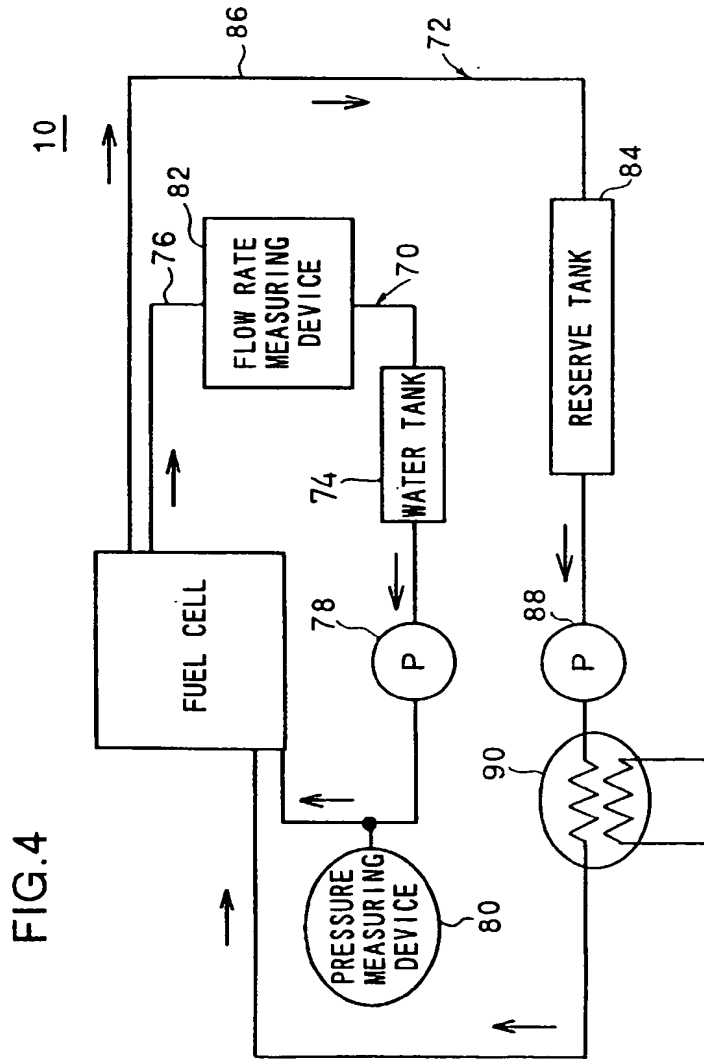


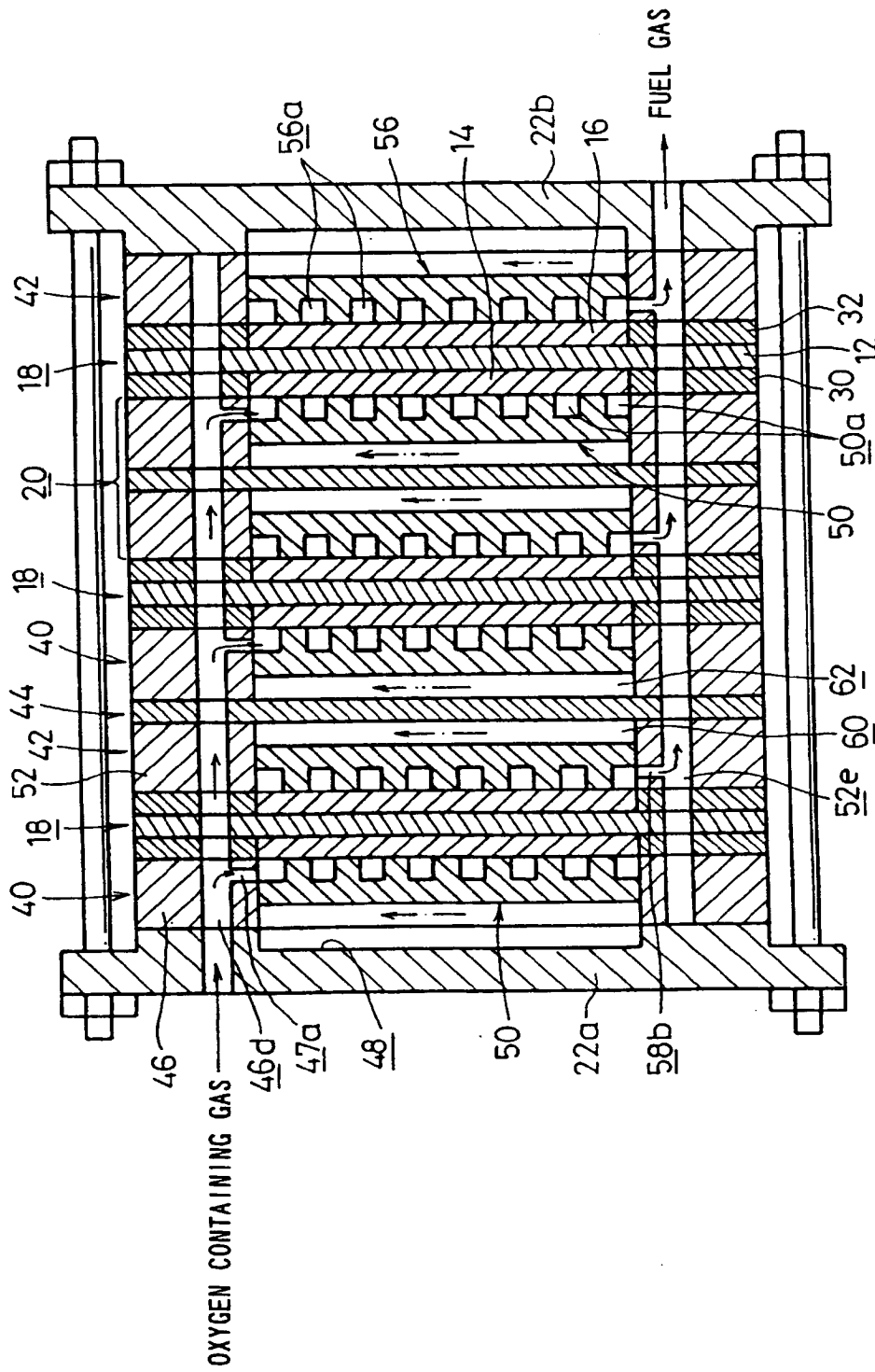
FIG. 2

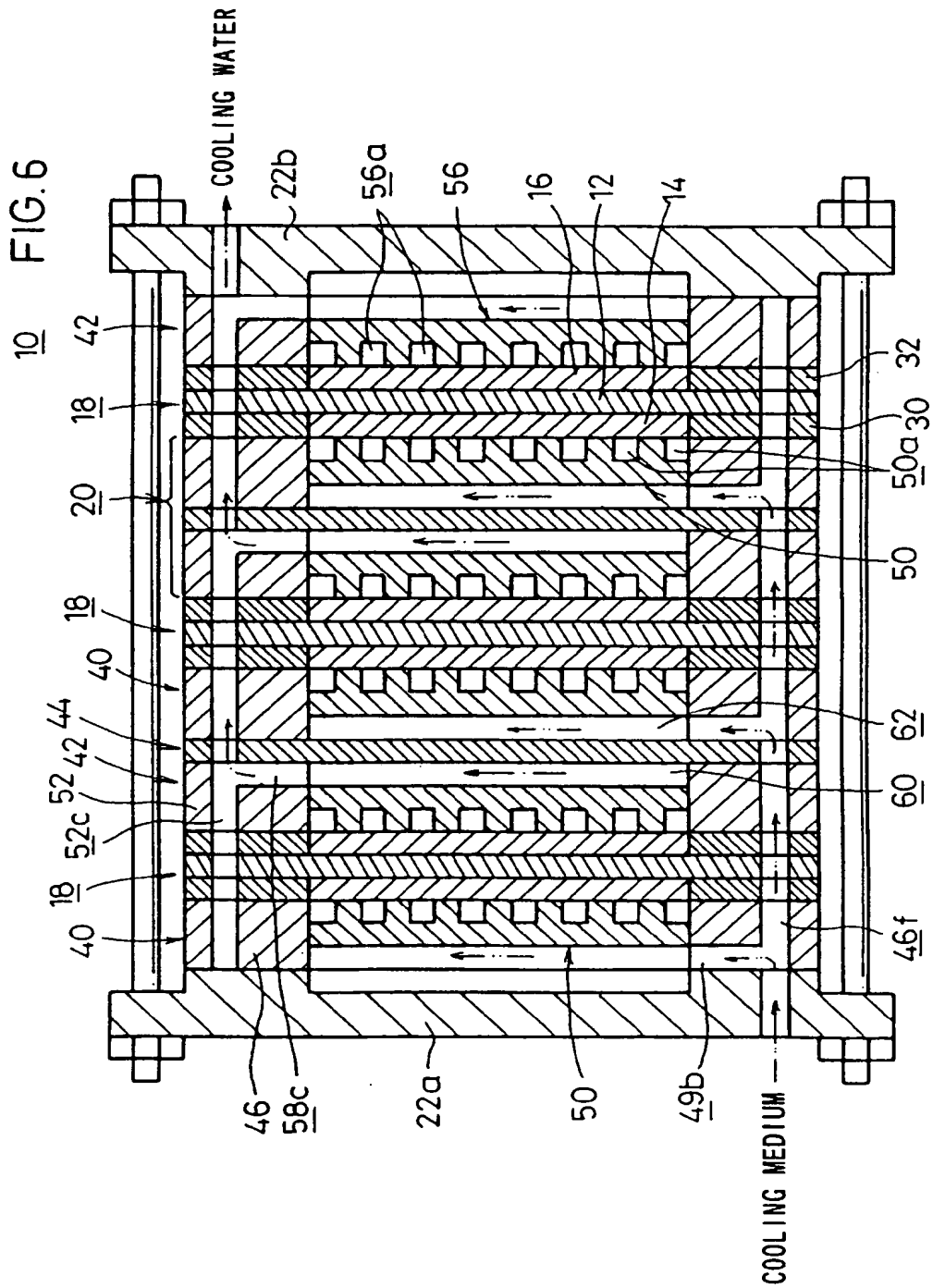


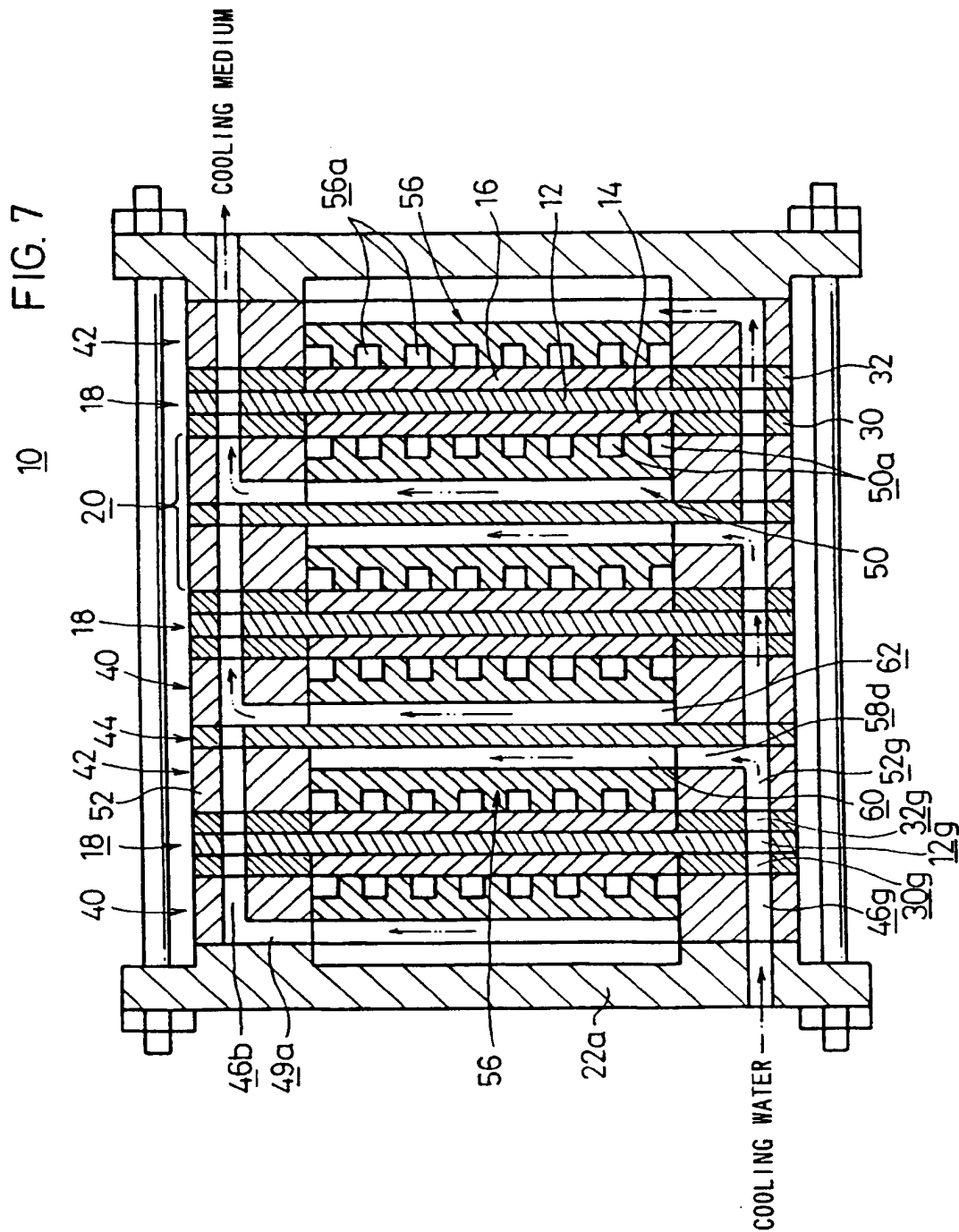


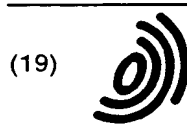


10 FIG. 5









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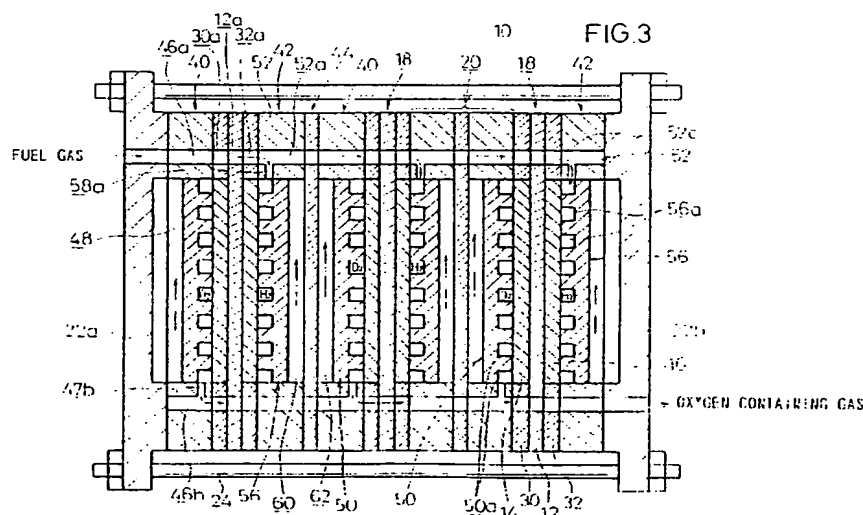
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(54) Fuel cell stack with dual cooling system

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medium, generally composed of water, is introduced for cooling the hydrogen-side electrode, and a second cooling passage (62) through which a second cooling medium having a melting point below that of water is introduced for cooling the air-side electrode. Accordingly, a melting operation for the first cooling medium can be easily and swiftly carried out, while the fuel cell unit itself remains simple in structure.





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## EUROPEAN SEARCH REPORT

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EP 97 30 6007

DOCUMENTS CONSIDERED TO BE RELEVANT			
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.6)
A	PATENT ABSTRACTS OF JAPAN vol. 095, no. 010, 30 November 1995 & JP 07 169489 A (TOSHIBA CORP), 4 July 1995, * abstract *	1-7	H01M8/04
A	--- PATENT ABSTRACTS OF JAPAN vol. 012, no. 192 (P-712), 4 June 1988 & JP 62 297912 A (MITSUBISHI HEAVY IND LTD), 25 December 1987, * abstract *	1-7	
A	--- PATENT ABSTRACTS OF JAPAN vol. 096, no. 011, 29 November 1996 & JP 08 195214 A (MITSUBISHI ELECTRIC CORP), 30 July 1996, * abstract *	1-7	
A	--- PATENT ABSTRACTS OF JAPAN vol. 095, no. 011, 26 December 1995 & JP 07 226223 A (OSAKA GAS CO LTD), 22 August 1995, * abstract *	1-7	
P,A	--- EP 0 741 428 A (FINMECCANICA SPA) 6 November 1996 * column 5, line 23-29 * * column 6, line 17-41 * * figure 1 * -----	1-7	TECHNICAL FIELDS SEARCHED (Int.Cl.6)  H01M
The present search report has been drawn up for all claims			
Place of search <b>MUNICH</b>		Date of completion of the search <b>12 January 1998</b>	Examiner: <b>Engl, H</b>
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